SIMULATIONS OF NOISE-PARAMETER UNCERTAINTIES

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IMS-2002, Seattle, June 6, 2002

OUTLINE

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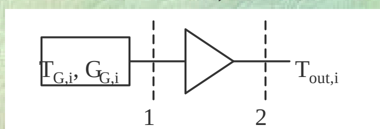
INTRODUCTION

- Problem addressed is propagation of errors in measuring noise parameters of an amplifier or transistor:
  - We know uncertainties in underlying measured quantities (G_i , T_{in} , S, T_{out})
  - Want to know uncertainties in the noise parameters (and gain) determined from the measurements.

- Complicating factors:
  - Overdetermined system of equations
  - Complicated dependence on the underlying variables (especially G's) and on the number of the input G's used
- Problem does not admit a simple, analytical solution.
- So use Monte Carlo simulation.

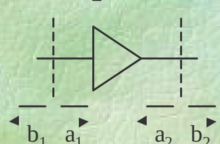
Process To Be Simulated

- Multiple input terminations $T_{G,i}$, $G_{G,i}$; measure output $T_{out,i}$ for each



- $T_{G,i}$, $G_{G,i}$, and S-parameters are known from other measurements, except $|S_{21}|^2$, which is determined in the noise measurements.

- Computations were done in terms of



$$k_B X_1 \equiv \left\langle \left|\hat{b}_1\right|^2 \right\rangle, \quad k_B X_2 \equiv \left\langle \left|\hat{b}_2 / S_{21}\right|^2 \right\rangle = k_B T_{e0},$$

$$k_B X_{12} \equiv \left\langle \hat{b}_1 \left(\hat{b}_2 / S_{21}\right)^* \right\rangle.$$

$$T_{out} = \frac{|S_{21}|^2}{\left(1-|\Gamma_{GS}|^2\right)} \left\{ \frac{\left(1-|\Gamma_G|^2\right)}{\left|1-\Gamma_G S_{11}\right|^2} T_G + \left|\frac{\Gamma_G}{1-\Gamma_G S_{11}}\right|^2 X_1 + X_2 + 2\,\mathrm{Re}\left[\frac{\Gamma_G X_{12}}{1-\Gamma_G S_{11}}\right] \right\}$$

but results will be given in terms of a version of the IEEE parameters,

$$T_e = T_{\min} + t \frac{\left|\Gamma_{opt} - \Gamma_G\right|^2}{\left|1+\Gamma_{opt}\right|^2 (1-|\Gamma_G|^2)}$$

Simulation Process

- Start by knowing true values of underlying quantities ($T_{G,i}$, $G_{G,ii}$, S) and their measurement uncertainties and distributions; also start with known noise parameters. For true values, use measured or hypothetical values.
- Generate a set of simulated measurement data for $T_{G,i}$, $G_{G,i}$, S, and $T_{out,i}$, *e.g.*,

  $T_{meas} = T_{true} + e_T$,

  where $< e_T > = 0$ and $< e_T^2 > = u_T^2$

- Analyze the simulated data as if it were real data, compute the "measured" noise parameters and gain ($|S_{21}|^2$).
- Repeat
- Compute uncertainties in noise parameters and gain,

$$u(y) \approx RMSE(y) = \sqrt{Var(y) + (\bar{y} - y_{true})^2} \ .$$

Details

- Particular case analyzed:

$|S_{21}|^2 = G_0 = 2399$ (33.80 dB)

$T_{e,min} = 109.6$ K ($F_{min} = 1.392$ dB)

$G_{opt} = 0.050 + 0.142$ j

$t = 176.3$ K

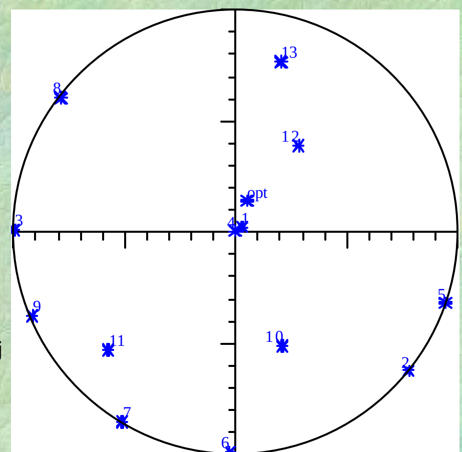
$S_{11} = 0.0181 - 0.1215$ j

$S_{22} = 0.1371 - 0.0300$ j

$S_{12} = 0.0018 + 0.0007$ j

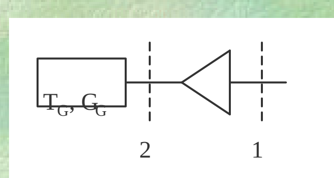
$T_{G,1} = 9920$ K, $G_{G,1} = 0.028070 + 0.022718$ j

$T_{G,i} = 296$ K (i = 2–13)



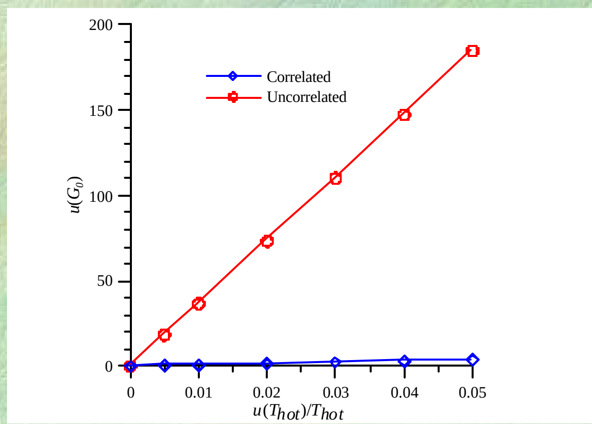
Distribution of $G_{G,i}$ in and on the unit circle

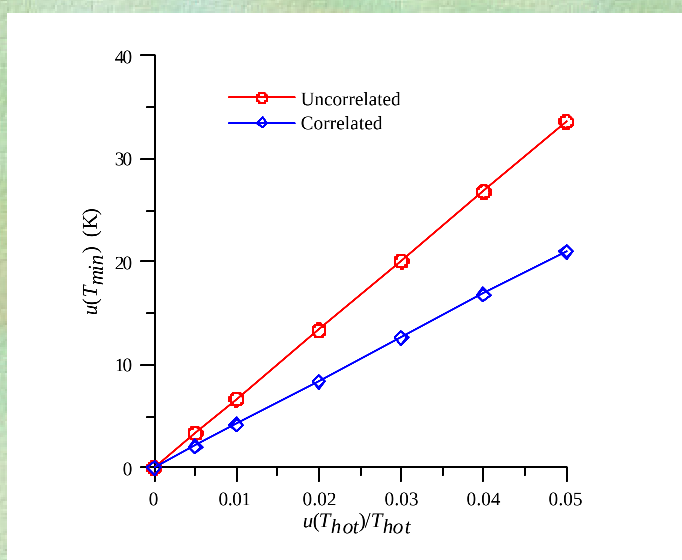
- 1000 simulations
- Allow correlations among errors in all the G's, all the T_{amb}'s, all the measured T_{out}'s.
- Also considered two possible enhancements:
  - Cold input noise source instead of, or in addition to, hot source
  - Measurement of the reverse configuration

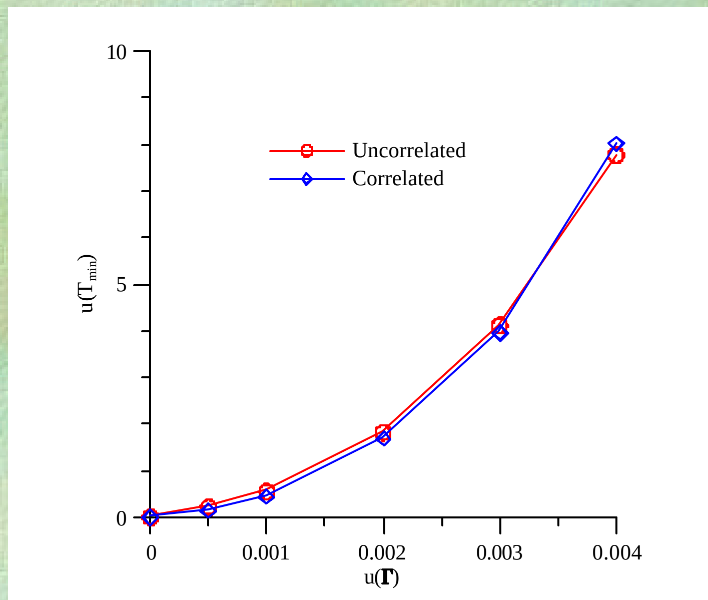


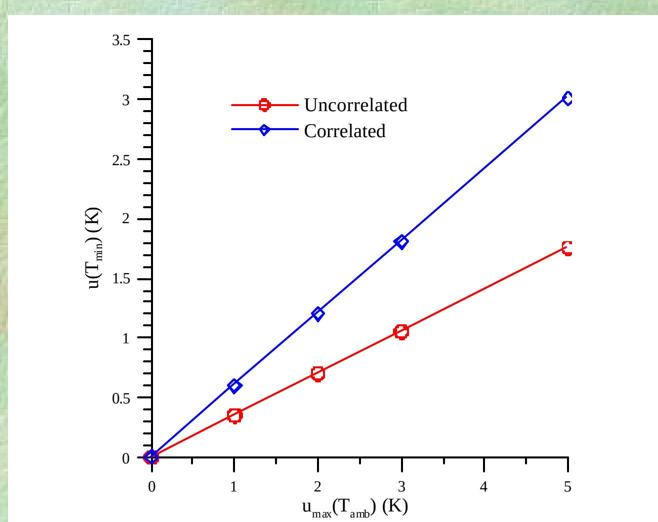
RESULTS

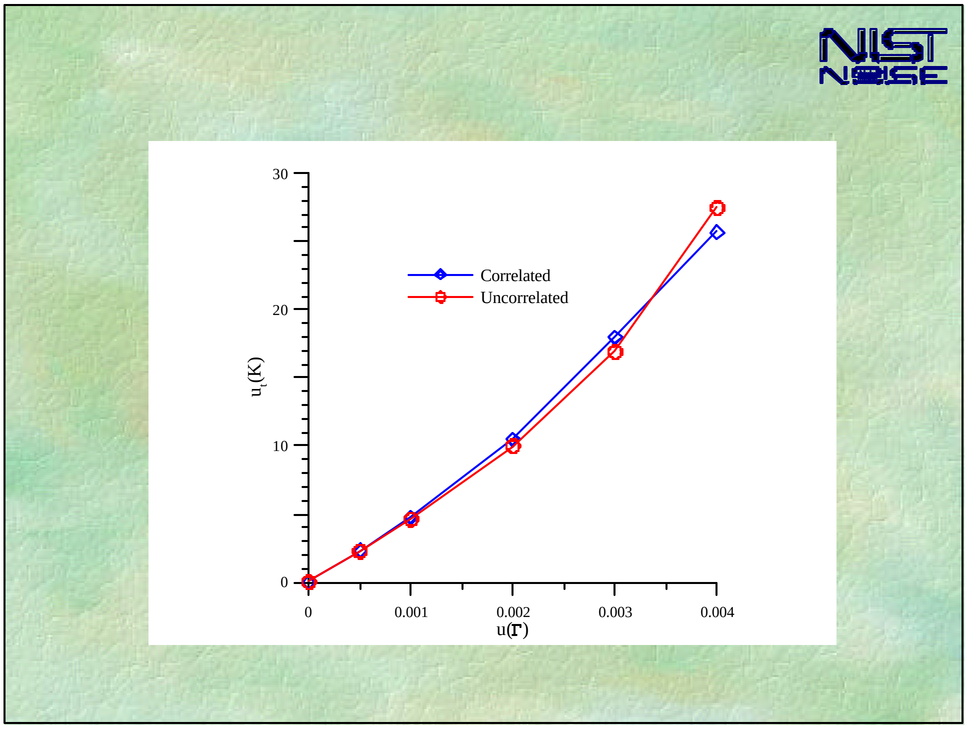
- Dependence on individual uncertainties (all other uncertainties = 0)

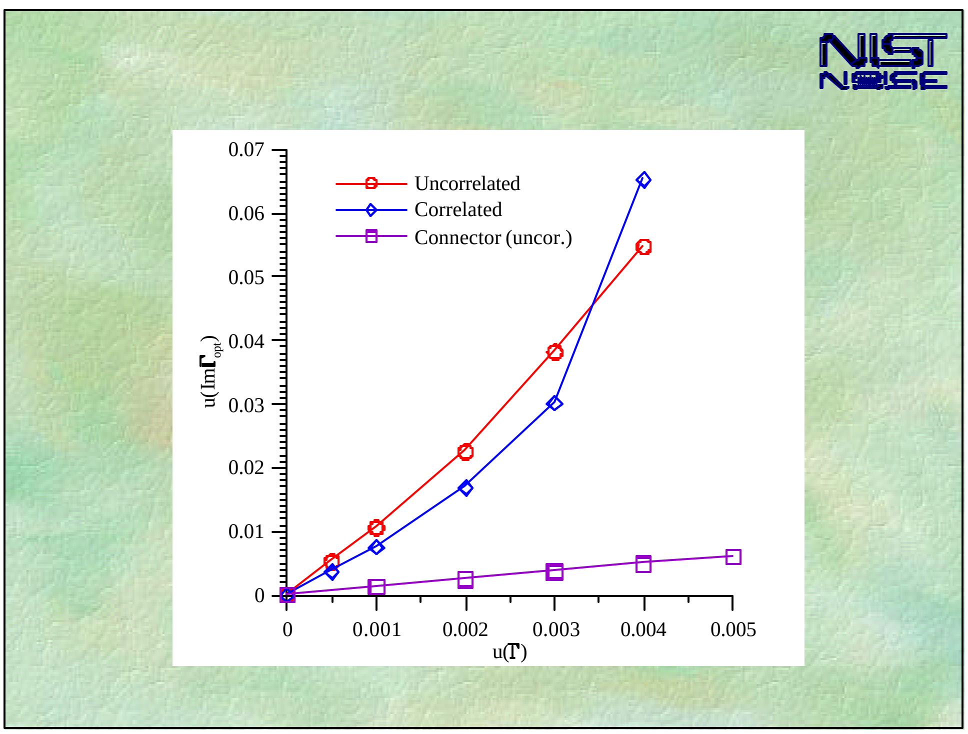


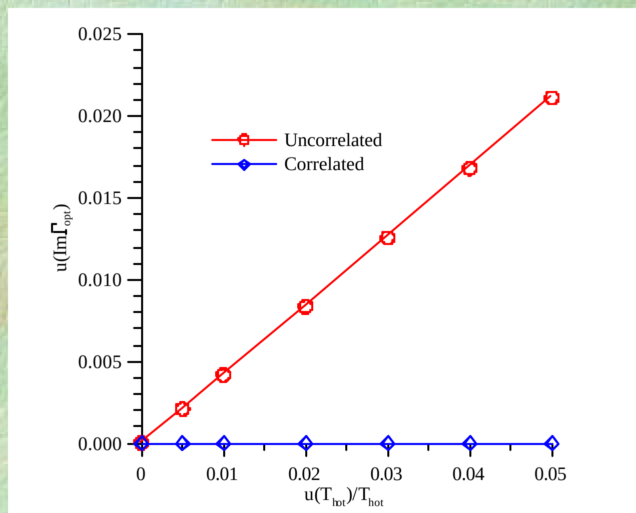



Uncorrelated
Correlated
u(T min)
10
5
0
0
0.001
0.002
0.003
0.004
u(Γ)


Uncorrelated
Correlated
u(T min) (K)
3.5
3
2.5
2
1.5
1
0.5
0
0
1
2
3
4
5
u max(T amb) (K)


NIST NOISE
Correlated
Uncorrelated
30
20
10
0
u_t(K)
0
0.001
0.002
0.003
0.004
u(Γ)


NIST NOISE
Uncorrelated
Correlated
Connector (uncor.)
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
u(ImΓ_opt)
0
0.001
0.002
0.003
0.004
0.005
u(Γ)



✦ Representative Cases

Table 1. Underlying Uncertainties Used in Representative Cases

Case	$u_{Th,,frac}$	u_{Ta}(K)	u_G	u_{con}
Average	0.020	1.0	0.004	0.002
Good	0.010	0.8	0.003	0.001
VG	0.005	0.5	0.002	0.001

Table 2. Noise-Parameter Uncertainties for Representative Cases

Case	u_G (dB)	u_{Tmin} (K)	u_{Fmin} (dB)	u_t (K)	u_{ReGopt}	u_{ImGopt}
Average	0.13	17.1	0.19	26.1	0.040	0.056
Good	0.07	8.8	0.10	16.9	0.026	0.034
VG-h	0.03	4.2	0.05	9.9	0.016	0.020

✦Possible Improvements

Table 3. Noise-Parameter Uncertainties for Alternative Strategies

Case	u_G (dB)	u_{Tmin} (K)	u_{Fmin} (dB)	u_t (K)	$u_{Re\Gamma opt}$	$u_{Im\Gamma opt}$
VG-h	0.032	4.23	0.05	9.92	0.016	0.020
VG-c	0.051	2.96	0.03	8.85	0.016	0.020
VG-hc	0.026	1.95	0.02	9.71	0.016	0.021
VG-hr	0.040	6.81	0.08	10.94	0.017	0.020
VG-cr	0.066	7.25	0.08	11.71	0.017	0.020
VG-hcr	0.038	6.31	0.07	10.94	0.017	0.020

SUMMARY & FUTURE

✦ Summary

- Computed dependence on individual underlying uncertainties:
  - Uncertainty in gain is due almost entirely to u_{Thot} and u_{Tout} .
  - Uncertainty in T_{min} is due primarily to u_{Thot} and u_{Tout}, but u_G also can be significant.
  - u_{Thot} u_{Tout}, and u_G all contribute to uncertainty in t.
  - u_G is most important contribution to uncertainty in Γ_{opt} ; u_{Tout} also contributes.

- Connector variability and T_{amb} uncertainty not too important (unless extreme).
- Correlations increase some uncertainties, decrease others.

- Uncertainties for a few representative cases computed.
- Effect of supplementary measurements:
  - Use of a cold source instead of a hot source improves determination of T_{min}, degrades gain; use of both hot & cold improves both T_{min} and gain significantly.
  - Measurement of reverse configuration actually hurts determination of IEEE parameters.

Extensions and future plans

- Other values, develop empirical rules?
- Compare different strategies
- Use it to evaluate uncertainties in NIST measurements
- Extensions
  - version for output power measurement
  - magnitude & phase uncertainties for G's
- User-friendly version; distribute?

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